12.—Ashbed and Nutrients in the Growth of Seedlings of Karri (Eucalyptus diversicolor F.v.M.)

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When karri seedlings were grown in pots of soils from karri forest areas they showed remarkable responses to nitrogen and phosphorus fertilizers. The addition of nitrogen or phosphorous fertilizers separately gave only small increases in yield of seedlings, while the simultaneous addition of both fertilizers gave very large responses (up to three-fold in height and twenty-fold in dry weight).

Responses to ash and to heat treatment of the soil were also obtained. The major part of the ash response was shown to be due to the supply of phosphorus in the ash. The heat response is also believed to be largely due to increased supply of nutrients.

It is suggested that part of the well known ashbed response of karri forests is due to nutrients released in the ashing process.

Introduction

Growth of karri *(Eucalyptus diversicolor* F.v.M.) seedlings in the south-west of Western Australia is stimulated considerably in ashbeds where heaps of forest slash have been burned (Loneragan, 1961). Growth of young karri seedlings in non-ashbed areas is generally so poor that deliberate creation of ashbeds has become part of karri forest regeneration practice.

Karri ash contains plant nutrients including phosphorus, calcium, magnesium, and potassium (Stoate, 1950; Hatch, 1960) which may be important in the ashbed response. However, other marked chemical and physical changes are associated with ashbed treatment (Hatch, 1960) and no nutrient responses of karri have been recorded.

The work described in this paper was undertaken to assess nutrient deficiencies of a number of karri soils for optimum growth of karri seedlings, and to see to what extent nutrients might account for some of the stimulating effects of ashbeds.

Methods

Experiments 1, 2, 3.

General.—A red-brown sandy loam (karri-type) soil was taken from an area which showed typical ashbed response in regenerating karri seedlings at Crowea, 20 miles south of Manjimup. Soil from the top six inches was sieved, mixed, and 3,000 g placed in plastic bags in unglazed earthenware containers of 8-inch diameter at the surface.

All fertilizer additions are expressed as weight/acre calculated from a surface area basis (1 cwt/acre = 0.405g/pot). The plastic bags were perforated so that the soil was freely drained. The pots of soil were kept in the open at the Forests Department, Manjimup.

Karri *(Eucalyptus diversicolor)* seeds were sown in all pots on August 11 and 12, 1961. Natural rain was supplemented by de-ionised water as required. Plants were thinned to 5 per pot on October 2, to 3 per pot on October 30, and to 1 per pot on December 6.

The heights of plants from cotyledonary node to growing point was measured at frequent intervals throughout the experiment: data in tables refer to heights on April 26, about two weeks prior to harvest. At this time the thickness of the stem just above the cotyledonary node was also measured with calipers.

Shoots and roots of plants of experiments 1 and 3 were separated at the cotyledonary nodes and harvested on May 4 and 3, 1962, respectively: plants of experiment 2 were not harvested.

Harvested material was dried in an oven at 105°C, cooled in a desiccator, and weighed.

Detail.—*Experiment 1*—To test the effects of nutrients on the ashbed response of karri seedlings on karri-type soil.

No basal fertilizers were applied. Treatments were applied in quadruplicate, in a 2 x 2 x 2 factorial design as follows:

- Heat—nil or 12 hours at about 150°C in an oven: the soil was placed directly in the earthenware pot for this purpose: the plastic bag was replaced after treatment.
- Ash—nil or 3 tons of ash/acre. Ash was collected from tree bark which had been burned in a hot fire; it was mixed throughout the top inch of soil.
- Nutrients—nil or N, P, K, Ca, Mg, Mn, Cu, Cl, Zn, B, Mo, Co. The nutrients were added as the same salts, at the same rates, and in the same manner as were used for basal and for treatment dressings in experiment 2, with the omission of NaH_2PO_4.

Experiment 2—to test the response of karri seedlings on karri-type soil to applications of K, Ca, Mg, S, Mn, Cu, Cl, Zn, B, Mo, and Co fertilizers.

Basal dressings of nitrogen and phosphorus were applied. NH_4NO_3 was applied at 14 cwt/acre in aliquots of 1 cwt/acre to the soil surface at regular intervals. Phosphate was applied as either the sodium or the potassium salt at levels equivalent in phosphate to 4 cwt of superphosphate/acre.

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Treatments were applied in an unreplicated 2^5 factorial design as follows:

KH_2PO_4 at 1.5 cwt/acre or NaH_2PO_4 at 1.3 cwt/acre

$CaCO_3$ — nil or 2 cwt/acre

$MgSO_4$ — nil or 56 lb/acre

$MnSO_4.4H_2O + CuSO_4.5H_2O + ZnSO_4.7H_2O$ — nil or 14 + 7 + 7 lb/acre

$Na_2B_4O_7.10H_2O + (NH_4)_6.Mo_7O_{24}.4H_2O + CoCl_2.6H_2O$ — nil or $3\frac{1}{2}$ + 1 + 1 lb/acre.

All salts except $CaCO_3$, which was applied in solid form, were applied in solution to the surface of the soil. When all salts had been applied they were mixed through the surface inch of soil.

Experiment 3—To test the response of karri seedlings on karri-type soil to applications of N, P, and K fertilizers.

Basal dressings of salts of Ca, Mg, S, Mn, Cu, Cl, Zn, B, Mo, and Co were applied. The nutrients were applied as salts in the same form, rate, and manner as the nutrient treatment in experiment 2, with the omission of KH_2PO_4 and NaH_2PO_4.

Two treatments were applied in octuplicate in a 2 x 2 factorial design as follows:

KH_2PO_4 — nil or 1.5 cwt/acre applied in solution to the soil surface.

NH_4NO_3 — nil or 14 cwt/acre applied as in experiment 2.

Experiment 4.

Loamy sand was taken from the surface of soils in two adjacent areas on either side of a narrow jarrah-marri (*Eucalyptus marginata-E. calophylla*) and karri-marri ecotone at Snake Gully near Manjimup (see Plate 1, Loneragan, 1961).

The soils were prepared at the same time and in the same way as the karri soil used in experiments 1, 2, and 3, with the exception that six-inch diameter pots were used. (O.23 g of fertilizer/pot 1 cwt/acre).

A simple experiment was designed to test the effects of nitrogen and phosphorus fertilizers on the growth of karri seedlings on the karri-marri and the jarrah-marri soils.

The basal and treatment dressings of fertilizers were identical to those of experiment 3. The treatments were imposed in duplicate.

Experiment 5.

Loam was taken from ashbed and non-ashbed areas of the surface soil of a regenerating karri forest at Easter Brook, 20 miles west of Manjimup. Pots of soil were prepared as in experiment 4.

Treatments consisted of either no fertilizers or dressings equivalent to 10 cwt of commercial N. P. K mixed fertilizer ("Nitrophoska red") per acre. These were imposed in duplicate.

Seed was sown on 11 July, 1962, thinned to 1 plant per pot, and harvested on 15 may, 1963.

Experiment 6.

Loam was taken from ashbed and non-ashbed areas of the surface soil of a regenerating karri forest at Mattaband, 35 miles south-east of Manjimup. Pots of soil were prepared as in experiment 4.

Treatments were applied in duplicate as follows:

N — nil or 10 cwt of calcium ammonium nitrate/acre.

P — nil or 10 cwt of lime-super/acre.

Karri seeds were sown on 1 June, 1962, thinned to 1 plant per pot, and harvested on 15 May, 1963.

Experiments 7, 8.

General.—Soil was taken from the same area as in experiments 1, 2, and 3. Soil from the top six inches was mixed and 1,800 g placed in plastic bags in polystyrene containers of 6-inch diameter at the surface (O.23g fertilizer/pot = 1 cwt/acre). The containers were not drained and the water content of the soil was maintained around field capacity by adding deionised water to weight. The plants were grown in a glasshouse at Perth: the glasshouse was shaded to about half natural daylight from December 1.

Karri seeds were sown in all pots on August 8, 1962. Plants were thinned to 5 per pot on September 11, and to 1 per pot on November 16. Tops of plants were harvested on December 19, 1962 and treated as in experiments 1, 2, and 3.

Detail.—*Experiment 7*—To test if some of the response of karri seedlings to ash is due to supply of phosphate.

Basal dressings were applied of salts of N, K, Mg, S, Mn, Cu, Zn, B, Mo, and Co. N was applied in solution as NH_4NO_3 in aliquots of 1 cwt/acre given at intervals throughout the experiment to give a total of 4 cwt/acre. All other basal nutrients were applied in the same form and at the same rate as in experiment 3; in addition, K_2SO_4 was applied in solution at 2 cwt/acre. The basal dressings were pipetted on the soil surface, allowed to dry, and mixed thoroughly with all the soil in the pot.

Treatments were applied in quadruplicate in a 4 x 4 factorial design as follows:

P — phosphate equivalent to superphosphate at O, 4, 10, or 25 cwt/acre: the replicates were split into pairs which received either KH_2PO_4 or NaH_2PO_4 in solution at appropriate rates.

Ash — O, 1, 3, or 9 tons/acre: ash was prepared as in experiment 1.

After application, the treatments were allowed to dry and were mixed thoroughly through the volume of the soil.

Experiment 8—To test if the response of karri seedling to ash is due in any way to an effect on nitrogen supply.

Basal dressings were applied of salts of P, K, Mg, S, Mn, Cu, Cl, Zn, B, Mo, and Co. The salts were applied in the same forms and at the same rates as in experiment 2, with the omission of NaH_2PO_4 and $CaCO_3$, and the inclusion of K_2SO_4 at 2 cwt/acre. The basal dressings were pipetted on the soil surface, allowed to dry, and mixed thoroughly with all the soil in the pot.

Treatments were applied in quadruplicate in a 2 x 2 factorial design as follows:

NH_4NO_3 — nil or 4 cwt/acre applied in solution in aliquots of 1 cwt/acre.

Ash — nil or 3 tons/acre: ash was prepared and mixed as in experiment 4.

Fig. 1. Effects of ash, heat, and nutrients on the growth and form of karri seedlings grown for eight months in pots of karri topsoil (Experiment 1). Top—no heat. Bottom—heat treatment of soil before planting. Left to right—no ash, no nutrients; no ash, + nutrients; + ash, no nutrients; + ash, + nutrients.

Results

Ash, heat, and nutrient responses

Ashbed treatments markedly stimulated the growth of karri seedlings grown in pots of karri soil (Table 1). Application of ash, in the absence of nutrients and of heat treatments, increased the height of the seedlings one-and-a-half times, doubled the stem diameter, and trebled the dry matter of tops and roots. Heat treatment of the soil prior to sowing also gave, in the absence of ash and of nutrients, similar large increases in seedling growth.

TABLE 1

Effects of ash, heat, and nutrients on the growth of karri seedlings for eight months in pots of karri topsoil (Experiment 1).

	Nutrients	No Heat		Heat	
		— Ash	+ Ash	— Ash	+ Ash
Dry weight of shoot (g x 10^{-1} per plant)	—	7	26	35	79
	+	162	271	259	353
Height of shoot—cm.	—	27	41	45	59
	+	66	83	76	87
Diameter of stem—cm. x 10^{-2}	—	14	26	24	37
	+	52	57	60	65
Dry weight of shoot—percentage maximum	—	2	7	10	23
	+	46	77	73	100
Height x girth percentage maximum	—	1	7	7	22
	+	48	73	74	100

All main treatment effects, significant at $P < 0{\cdot}001$: all interactions, not significant. Dry weight data were transformed to square roots before analysis.

Nutrients applied to the same soil stimulated karri seedling growth to an even greater extent than ashbed treatments (Table 1). In the absence of ash and heat treatments, nutrients nearly trebled height growth and stem diameter and increased dry matter production twenty-fold. The more striking stimulation of dry matter production, compared with height and stem diameter, was partly due to the effects of nutrients in increasing branching and leaf production (Fig. 1) and partly due to the fact that the weight of the main stem increases with a function of the product of its height and square of its diameter. Despite the striking effects of treatments on seedling form, the product of height x girth reflected relative effects of treatment on dry weight production very closely (Table 1).

In the presence of ash and heat treatments, nutrients again increased growth of karri seedlings. Interactions between treatments were in all cases not significant.

The nature of the nutrient response

The striking effect of the nutrient mixture in stimulating karri seedling growth was due almost entirely to the supply of nitrogen and phosphate in the mixture. None of the nutrients K, Ca, Cu, Mn, Zn, Co, Cl, B, or Mo, was deficient in the soil since, when nitrogen and phosphate were applied, the omission of any of them had no effect at all on the appearance, shoot height, or stem diameter of karri seedlings. The omission of $MgSO_4$ from the nutrient mixture had no effect on shoot height, but depressed stem diameter slightly (by 13%: significant at 5%). No dry weight data were collected on plants of this experiment. On the other hand, the failure to supply either nitrogen or phosphorus to the seedlings, even in the presence of all other nutrient salts, led to severe restriction of growth (Fig. 2).

For optimum seedling growth, nitrogen and phosphorus appear to be deficient in many karri forest soils. Large responses of karri seedlings were obtained when nitrogen and phosphorus fertilizers were applied to pots of all soils examined (Table 2).

TABLE 2

Effects of nitrogen (N) and phosphorus (P) fertilizers on the growth of karri seedlings grown in pots of various soils from karri forest areas (Experiments 4, 5, 6)

Dry weight of shoots (g x 10^{-1} per plant)

	—N —P	—N + P	+N —P	+N +P
Snake Gully (karri-marri) ...	8	16	17	96
Snake Gully (jarrah-marri)	2	4	4	109
Easter Brook (ashbed)	20	....	....	77
Easter Brook (non-ashbed)	21	....	....	76
Mattaband (ashbed) ..	11	....	...	86
Mattaband (non-ashbed)	4	14	21	91

The nature of the ash response

Phosphorus.—A major part of the effect of ash in stimulating karri growth on soil in pots was due to an increase in phosphorus supply to the plant (Table 3). As in previous experiments, karri seedlings grew poorly when phosphorus was omitted from the soil to which all other known essential nutrients were added. In the absence of phosphorus, addition of ash up to 9 tons per acre increased dry matter production of the shoots six times. But in the presence of phosphorus the response to ash disappeared (interaction significant at $P<0.001$).

TABLE 3.

Effects and interactions of phosphate fertilizers and ash on the growth of karri seedlings grown for four months in pots of karri topsoil given adequate dressings of other nutrients (Experiment 7).

Dry weight of shoots (g x 10^{-1} per plant).

Ash Tons/acre	Form of Phosphate	Phosphate (= P in cwts super/acre) 0	4	10	25
0	Na	4	67	69	76
	K	4	66	70	50
1	Na	8	69	66	74
	K	7	71	77	77
3	Na	12	72	72	81
	K	13	77	79	84
9	Na	18	73	82	77
	K	28	70	84	75

The response of karri seedlings to ash in this experiment is thus due to its effect on phosphorus supply. This effect is explained by the phosphorus actually added to the severely phosphorus-deficient soil in the ash (0.3%). A dressing of 9 tons of ash per acre would contain

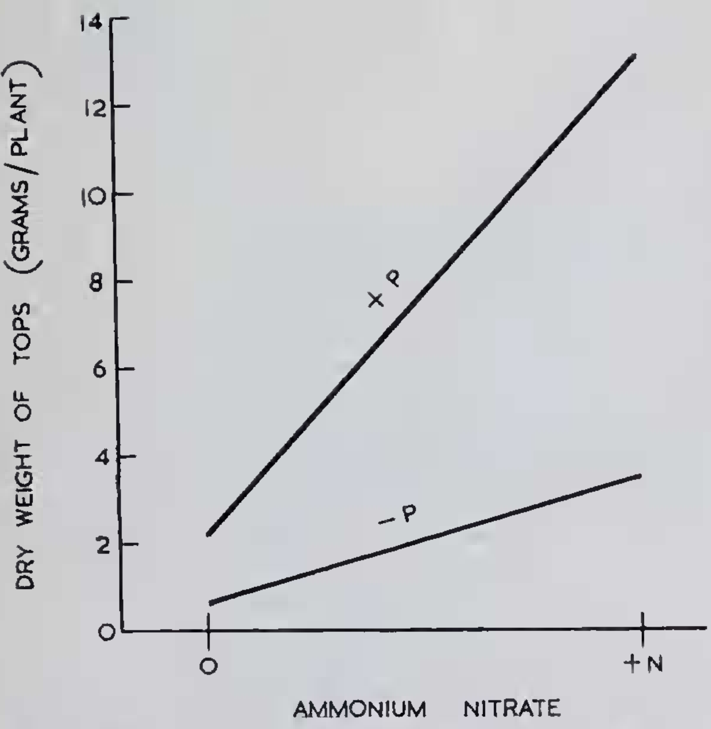

Fig. 2.—Effect of ammonium nitrate (N) and potassium phosphate (P) on the growth of karri seedlings grown in pots of karri topsoil given adequate levels of other nutrients (Experiment 3). Interaction significant at $P<0.001$.

phosphorus equivalent to 6 cwt of superphosphate per acre. The failure of this treatment to stimulate growth of karri to the same extent as equivalent dressings of phosphate salts was probably due to poorer availability of the phosphorus from the ash.

Nitrogen.—In addition to increasing phosphorus supply to karri seedlings, ash treatment increased nitrogen supply to an appreciable extent (Table 4). In the presence of all known nutrients except nitrogen, karri seedling growth was again poor. In the absence of nitrogen, addition of ash doubled the yield of shoots. In the presence of nitrogen there was no response at all to ash (interaction significant at $P<0.001$). Thus, in this experiment the response to ash must have been due entirely to an effect in increasing nitrogen supply.

TABLE 4

Effects and interaction of ammonium nitrate and ash on the growth of karri seedlings grown for four months in pots of karri topsoil given adequate dressings of other nutrients. (Experiment 8).

Dry weight of shoots (g x 10^{-1} per plant)

	— Ash	+ Ash
No ammonium nitrate	8	19
+ ammonium nitrate	86	86

The ash contained no measurable nitrogen, so that its effect on nitrogen supply must have been indirect.

Other factors.—Although in experiments 7 and 8 all of the ash response was replaced by nutrients, in experiment 1 there was some response to ash even in the presence of nutrients. The additional response given by ash in the presence of nutrients was probably partly due to the supply of sub-optimal amounts of nitrogen in the nutrient treatment, combined with heavy leaching in the early stages of growth. However, it is still possible that in experiment 1 a small part of the ash response in the presence of nutrients was due to factors other than nitrogen and phosphorus supply. Because of small differences in experimental technique (e.g. size and drainage of the pots, depth of mixing of treatments, water supply), it is not possible to make an absolute comparison between experiment 1 and experiments 7 and 8.

However, it is clear that under all conditions, nitrogen and phosphorus supply are the major limiting factors to the growth of karri seedlings on the soils examined. It is also clear that the prime effect of ash is to increase the supply of phosphorus.

Discussion

A number of soils from karri forests have been shown to be extremely deficient in both nitrogen and phosphorus for the growth of karri seedlings. Soils from regenerating *Eucalyptus obliqua* forests have previously been shown to be deficient in phosphorus for growth of *E. obliqua* seedlings (Attiwill, 1962). It seems, then, that the growth of seedlings and perhaps also of trees regenerating in eucalypt forests may be limited by the same widespread deficiences of nitrogen and phosphorus which limit the growth of agronomic crops on so many Australian soils.

Beadle (1954, 1962) has in fact suggested that soil phosphorus status is an important determinant of plant communities in *Eucalypt* forest areas of eastern Australia. In addition, he has shown a marked response of the seedlings of three *Eucalypt* species to soils with increasing phosphorus status. His photographs show changes in leaf size and seedling form with increasing soil phosphorus similar to those produced by nutrients in karri seedlings.

The striking nutrient responses of karri seedlings reported in this paper should not be extrapolated directly to the forest. The results were obtained with seedlings grown for a very short period of time, in the absence of competition, and with adequate water. All of these conditions are modified in the forest. Moreover, nutrient treatments in pots caused dramatic changes towards a different form of the karri seedlings. However, the results do indicate the potential which exists for stimulation of tree growth by adding fertilizers to karri forest soils.

Heat treatment of soils and dressings of wood ash also stimulated growth of karri seedlings. The effects of ash were shown to be largely due to increased phsophorus supply to the seedlings. Heat treatment of forest soil has also been shown to liberate phosporus for the growth of *Eucalyptus obliqua* seedlings (Attiwill, 1962). In addition, heat treatment of the same soil appears to have released some nitrogen to the seedlings. There are reports of increased supply of nitrogen from organic matter after heating (Vlamis *et al.*, 1955), although there may, in fact, be a loss of total nitrogen from the soil through burning (Barnette and Hester, 1930). It is suggested that in the present experiment the main effects of heat may also have been through the release of nutrients for the growth of karri seedlings. No attempt was made in this work to resolve the effects of heat.

Even when the soil had been heat treated and large quantities of ash applied, nutrients stimulated karri seedling growth. This suggests that ashbed responses in the forest could be greatly augmented by fertilizers. Such fertilizers would probably be best applied at the earliest opportunity to encourage trees to dominate the site.

In some pot experiments, nutrients replaced ash. However, the effects of fire which produce ashbeds in the forests are complex (see review by Ahlgren and Ahlgren, 1960). Therefore, extrapolation to the forest situation of the effects of heat and ash treatments on the growth of karri seedlings in pots has even more limitations than the extrapolation of nutrient responses. Marked effects of burning forest slash on the physical and chemical properties of the soils in karri forests have been recorded by Hatch (1960). In addition to these effects, burning of forest slash may modify the viability of seed and therefore the regeneration of plants in the vicinity. Heat from the fire may destroy surface roots and seeds of competitive species, and so permits unhindered germination and growth of seed freshly introduced from above by seed trees in the area. This competition-free seed bed may be an important part of the ashbed response in karri regeneration (Loneragan, 1961). At the same time, the ability of seeds of some *Acacia* species to germinate is increased by mild heat conditions on the fringe of the ashbed, so that leguminous species may be favoured to colonize the fringe areas of the ashbed. In the long term, these species could be expected to improve the nitrogen status of the soil. Such changes in the botanical composition of the competitive species produced by ashbeds could produce marked changes in the competition which the karri suffers for light, nutrients, and water.

Whatever the complexity of the long term ashbed response, the results presented in this paper clearly indicate that nutrients supplied by ashbeds could make an important contribution to the accelerated growth of young karri seedlings in the ashbeds of regenerating forests.

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